COLLABORATIVE VISUALIZATION IN MEDICINE

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ABSTRACT

One of the biggest areas of scientific visualization (*ViSC*) application is Medicine: with the evolution of image acquisition techniques the capacity and fidelity of image diagnosis were extended. Due to the large number of medical exams that output images, several visualization systems have been developed dealing with specific problems in this area in the last few years. The growing of World Wide Web-based applications and the modern trend of cooperative work in scientific research gave rise to a new class of systems, the so-called collaborative visualization systems. This survey presents an overview of ViSC in Medicine emphasizing the different approaches for collaborative visualization, and discussing difficulties still found for its real utilization.

Keywords: Interactive Visualization, Visualization of Medical Images, Collaborative Visualization.

1. INTRODUCTION

The technological progress of the last few years confirmed the value of information in our society and led to the widespread use of computers, mainly the Internet. Graphical user interfaces were essential in this popularization of computer technology. New uses of faster computers and modern data gathering instruments have generated extremely large volumes of data that need to be represented in ways that facilitate their understanding. In the 80's, Computer Graphics and Image Processing techniques started to be used to build visual representations of data in several applications, giving rise to a new area, ViSC (Visualization in Scientific Computing). Techniques from this area allow the analysis, exploration through navigation processes, and efficient visual representations of data gathered from natural entities or phenomena or originated from scientific computing processes [Brodl92a, Earns92a].

For sure, one of the biggest areas of scientific visualization application is Medicine: with the evolution of image acquisition techniques, both in resolution and tissue distinctiveness, the capacity and fidelity of image diagnosis were extended [Rhode97a]. Once the medical image is obtained it has to be analyzed by a radiologist. Medical images are used to visualize the structure or function of parts of the human body and to detect when the characteristics of some disease are present. The physician could use the computer to manipulate the images, e. g. change the colors of an image, to allow a better visualization. Among Image Processing techniques, digital filtering (e.g. to remove noise), registration and segmentation are the most used in medical systems. Registration refers to the alignment process of several images obtained either from a single scanner or from different types of scanners [Weste96a]. Segmentation consists in dividing an image in parts according to its characteristics, and it is used to detect objects or regions of interest [Jain89a].

Nowadays, medical diagnosis in critical diseases, and scientific research in general are seldom executed by only one person. Often, in difficult cases, two or more physicians are involved to reach a diagnosis. Moreover, it might happen that there are no specialized physicians in the same city

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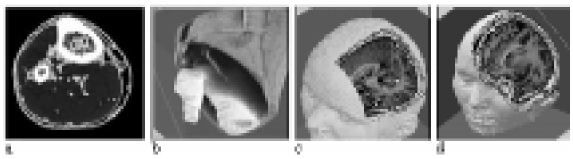
of a patient. With the growing of the *World Wide Web* (WWW), new technologies have been developed to make cooperative work possible. With these technologies collaborators in remote sites can simultaneously analyze the same set of scientific data. The support of the so-called collaborative visualization systems has to foresee simultaneous data visualization by several users and also the interaction among users and between users and data. So, we can have individual or collaborative visualization. Recently, this compelling area, called *Computer Supported Collaborative Visualization* (CSCV), is becoming more popular and important. In medical diagnosis, these applications are known as a Telemedicine sub-area, where Telemedicine consists in telecommunications technology used for interaction between health professionals and patients, or between physicians, with the goal of distance medical action fulfillment's.

The main goal of this survey is to overview visualization of medical data, emphasizing different approaches for collaborative visualization and discussing difficulties still found for its real utilization. Next section presents a brief description of interactive visualization tools for medical data, also including the use of virtual reality in simulation of surgeries. Collaborative visualization of volumetric data is described in section three. The last two sections summarize the main characteristics found in recent systems and the problems still to be solved to improve the application of this technology.

2. INTERACTIVE VISUALIZATION OF MEDICAL IMAGES

Volume Visualization denotes the set of techniques used in the presentation of volume data, i.e., data associated to positions (often regularly) spaced in some 3D domain. In general, volume visualization is a projection process of a multidimensional data set in a plane. Volumetric visualization techniques can be classified as surface visualization or direct volume rendering. Surface visualization algorithms usually separate the volume subset that represents a specific anatomical surface using segmentation. During the process, this volume subset is approximated by a set of polygons and exhibited with conventional computer graphics techniques. Examples are the contour technique [Keppe75a] and the marching cubes algorithm [Loren87a]. The second group of volume visualization techniques is based on a transfer function that establishes the relation between voxel values (denoting, for example, tissue density) and color/opacities. A well-known algorithm of this group is ray casting [Levoy90a]. While the surface visualization techniques are faster but present an approximation of the structure of interest, direct volume visualization techniques demand greater storage capacity and higher processing time, but display original data.

Initially, volume visualization algorithms were only developed to show the interior of the volume to allow the identification of its inner regions and structures and to facilitate the comprehension of its complex structure. Often, classification tables are used to assign colors and transparency levels to different intervals of voxel values. Later on, user interaction during the visualization process became important in order to allow the user to change parameters and perform a dynamic navigation process. Some examples of interactive visualization tools are: cross sections (Fig.1a), selection of different regions and structures (Fig.1b), cut volumes (Fig.1c), and cut planes (Fig.1d) [Silva97a].



Examples of interactive visualization tools.
Figure 1

A complex application of interactive manipulation of medical data is surgery simulation, which has gained higher importance in the last few years, especially because of its great utility in helping the training of new physicians. Simulators allow the achievement of virtual surgeries emphasizing real time interaction between the user and medical instruments, surgical techniques and models that represent several anatomical structures and physiologic processes. Many simulation systems exist nowadays, and most of them were developed to deal with a specific human body organ [Goble95a, Yagel96a] thus allowing researchers to study in detail one organ each time.

Surgery simulation has also been improved in the last few years with *Virtual Reality* (VR) techniques, which allow the development of virtual environments that are presented with so high accuracy that the user perceives it as real [Haase96a]. Many systems that join VR and medicine were developed in the last few years [Posto96a, Zajtc97a]. Moreover, haptic displays provide force feedback allowing users to feel the physical properties of the objects that are being manipulated [Srini97a]. However, some technical problems, such as precision, real time interaction, poor realism in the images, and absence of a convincing touch simulation still block the acceptance of this technology.

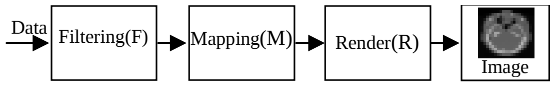
3. COLLABORATIVE VISUALIZATION

Computer Support for Cooperative Work (CSCW) is a new successful area concerned with the study of techniques to allow collaboration among several people in different places, working as a group to achieve a common goal [Palme94a]. Nowadays there are several high technology solutions to support cooperative work. Communication technologies are used to overcome the geographical separation of collaborators and to achieve the expected level of cooperation using teleconference, videoconference, electronic mail, and network documents management systems [Spurr94a].

In areas where results are presented as images, visualization can be executed in different places, at different moments, and of course by more than one person. Considering this and the growing of CSCW area, researchers of visualization techniques started to work in "collaborative visualization" systems. The term collaborative visualization refers to a subset of CSCW applications, known as CSCV, in which the control of parameters or results of a scientific visualization process are shared. The development of collaborative visualization systems presents many challenges due to the multi-user nature of these interactive applications [Johns98a].

Although several authors affirm that visualization is a collaborative activity, current visualization systems treat this as an individual activity. Scientists are provided with a great number of powerful systems as *IRIS Explorer*, *Application Visualization System* (AVS), *Khoros* and *IBM Data Explorer*. However, when using these systems scientists need to send the images throughout the network or to be physically together to verify the results. Due to this limitation, the developers of such systems started to work in their improvement to allow collaborative visualization. One example is the collaborative modules of AVS under development at San Diego Supercomputer Center. These new modules will increase AVS capabilities enabling multiple physically remote users to cooperatively interrogate the same scientific data using familiar visualization tools [Johns98a]. Since the researchers know how to work with the system (AVS), they are encouraged to adopt collaborative work habits.

The majority of visualization systems follow the *dataflow* model to implement the visualization pipeline, which has been detailed by Haber and McNabb [Haber90a] in their reference model. In this model, visualization is obtained in a three-process pipeline: filtering, mapping and rendering (Fig.2). The first process corresponds to the gathering of data from an entry process that could be an interpolation process to convert an irregular grid to a regular one and the selection of the desired resolution and region of interest. Mapping of the filtered data consists in transforming it to a geometrical representation, like an isosurface, and finally the rendering stage generates an image, animation or other product from the geometrical description [Wood97a, Johns98a].

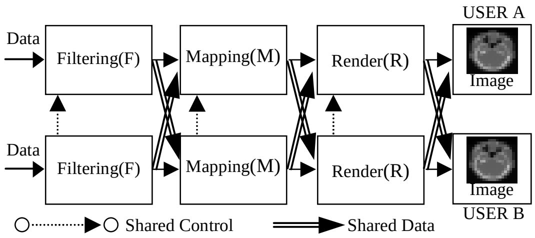


Visualization pipeline of Haber and McNabb.
Figure 2

Sharing of images obtained from a single data set can be achieved, for example, by duplicating all user interfaces in different workstations or producing identical images from the same data set in a synchronous way. In the latter case, besides the use of separated pipelines operating in different machines, the synchronization guarantee that the model consists in a single pipeline with multiples controls.

So, to achieve collaborative visualization the Haber and McNabb model can be extended to have intermediate entry and output points to control information and data [Wood97a]. To support several independent participants, there should be a visualization pipeline for each collaborator (Fig.3), and data and control information are exchanged at arbitrary points. Each stage could accept data and control information to permit their collaborative operation and exportation of data for sharing purposes. The control information of a pipeline could be exported to another to synchronize the collaboration. To share control, the user should define the control parameters locally, or this can be done externally by a collaborator. For example, if two users are collaborating in some mapping process, they could act in two ways. First, user A can export filtered data to the mapping stage of B and then they could exchange control information. However, if the filtered data should remain private to A, the users exchange control information in the mapping stage. In this case, the mapping stage of B consists only in a "ghost" process that generates appropriate control parameters to the mapping process of A.

Recently, according to the existent applications that provide visualization capabilities in collaborative context, Johnson [Johns98a] has categorized these systems by the level of shared control they provide over the visualization process. In the first category, *Local Control*, a collaborative visualization application consists of broadcasting image data to all participants. In this case, only the user creating the image(s) has direct interaction with the visualization process, while the other participants are limited to passive viewing of results and exchanging ideas, for example, via a telephone or teleconferencing software.



Reference model extension for CSCV[Wood97a]
Figure 3

The second category, *Local Control with Shared Data*, used in some collaborative AVS modules, is a more complex variation represented by applications in which participants can share data during any step in the visualization process. Direct interaction and control over the visualization process occurs locally. Partially or fully processed data can be shared. *Limited Shared Control* is the category represented by applications in which participants can share the others' viewpoints, and insert items into this shared view. Cooperative control of the visualization process is primarily limited to annotation of the resulting visual elements, and control of the view position. Finally, the *Fully Shared Control* category includes those applications that provide shared control over the parameters associated with a given visualization. These parameters may affect how a data set is filtered, mapped to graphical elements, and viewed, as well as aspects of the products output. Thus, the work of “steering” any aspect of the visualization process can be a shared activity. Shastra environment (section 4) and some AVS modules provide this kind of cooperative interaction [Johns98a].

4. CSCV AND MEDICAL SYSTEMS

Collaborative visualization systems applied to Medicine emerged as a set of techniques that deal with the problems of presenting images to remote collaborators and supporting interaction based on these images. They support Telemedicine, which is being used more and more in remote clinical consultation, and also to provide the possibility of assistant physicians to receive surgical directions from senior ones. Several collaborative systems have already been developed. In this section, TeleInViVo, SDSC_NetV, TeleMed and Shastra will be overviewed.

TeleInViVo [Colem96a] was developed at the Fraunhofer Center for Computer Graphics Research with the sponsorship of the *Defense Advanced Research Projects Agency* (DARPA) and the US Army *Medical Advanced Technology Management Office* (MATMO). It supports collaborative visualization and exploration of volumetric data including computed tomography, magnetic resonance imaging and *Positron-Emission Tomography* (PET). Using real-time visualization in a distributed environment, the main goal of TeleInViVo is to facilitate therapy planning and treatment, medical training, surgery, and diagnosis, since the physicians can exchange and manipulate the data sets via ISDN or ATM networks [Colem99a].

SDSC_NetV [Elvin96a] was developed as an experimental system at the San Diego Supercomputer Center. It is a distributed system with advanced rendering techniques and exhibits stereo images. It provides a friendly graphical interface and was designed to overcome the problems arising from the heavy processing of large volume of data used by volumetric visualization systems in the center's shared environment.

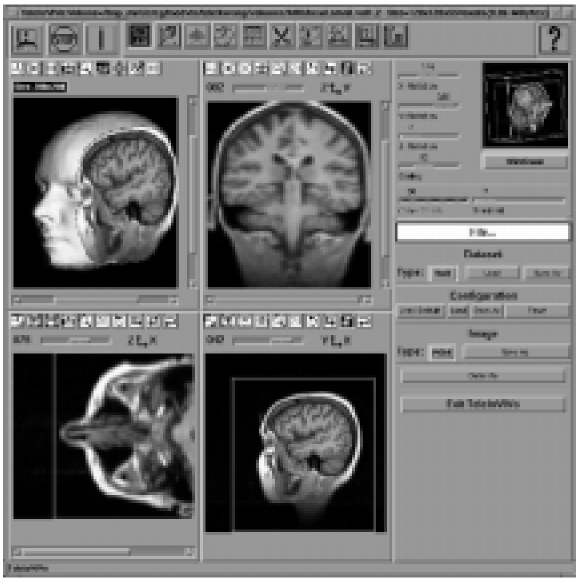
Los Alamos National Laboratory (LANL) in collaboration with the National Jewish Center for Immunology and Respiratory Medicine have recently developed a collaborative health-care environment system called TeleMed. This system is a prototype of the *Virtual Patient Records* (VPR), which provides a common format for visualization. It stores patient data in graphical format in such a way that physicians can query the data set without having to worry about data locality and movement. Its focus is to tie together enabling technologies, such as object-oriented distributed computing, graphical and multi-user interfaces, security and privacy into specific applications [Kilma97a, Forsl99a].

Shastra [Anupa94a] is a collaborative multimedia scientific manipulation environment in which experts in a cooperating group communicate and interact across a network to solve problems. Developed by a research group at the Purdue University (West Lafayette, US), Shastra allows distribution and collaborative visualization through the implementation of two distributed visualization algorithms. It consists of a group of inter-operating applications collectively called tools that provide managing, communication and rendering facilities.

While TeleInViVo and SDSC_NetV only run in UNIX environment, TeleMed is platform independent because it was developed using Java and *Common Object Request Broker Architecture* (CORBA). Shastra achieve platform independence by building applications with abstract libraries that hide hardware specifics. These abstract libraries can be easily extended to support standardized interfaces as they evolve.

Users of TeleInViVo are provided with a QuickCam^{TM} for videoconference and can use a six DOF ImmersionProbe^{TM} arm to locate and orient a three-dimensional plane in order to obtain new volume slices. Users of SDSC_NetV can wear liquid crystal glasses to observe stereo images, and a cyberglove for interacting with a shared immersive environment based on textured polygonal rendering. Shastra and TeleMed do not support VR hardware, but the second one can be launched through a Web-browser.

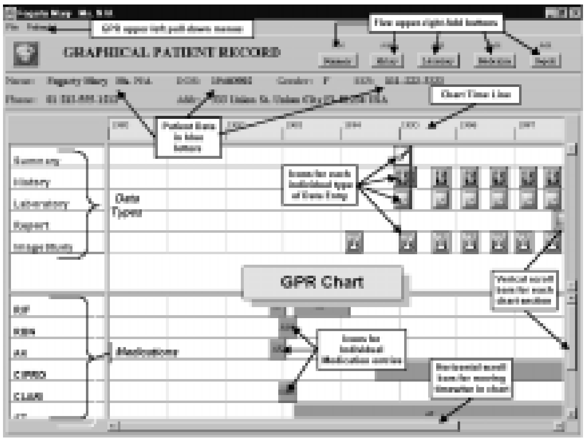
TeleInViVo was developed using an object-oriented approach unifying volume visualization, CSCW and telecommunications concepts. It is based on point-to-point communication with TCP/IP protocol. A session begins when a user calls another specifying an IP address. The caller user has the control over the other. The participants could return to the “stand-alone” mode at any moment. To optimize data transfer it is possible to transmit the data with a lower resolution and, after specifying the subset of interest, this is requested and transmitted with a higher resolution. TeleInViVo, which interface is presented in Fig.4, also provides tools for filtering, segmentation, volume visualization, isosurface construction, and arbitrary slice display.



TeleInViVo interface [Fraun99a]
Figure 4

The SDSC_NetV prototype manages the volume rendering resources available in the network, providing a friendly user interface based on Motif, through which the users can access several resources without knowing if they are locally or remotely located. To visualize volume data in motion, a pre-rendering is available, and then, the frames are exhibited in a loop.

TeleMed goal is to standardize the electronic management of patient information. TeleMed dynamically unites graphical patient records with the support for interactive collaboration in real time among multiple users. With this system several physicians can simultaneously access, edit and annotate patient data. TeleMed is called from a browser and an interface is downloaded. A login window is shown and authorized users can select a data base site. A patient can be selected through his/her name and the corresponding record is shown (Fig.5). Icons represent radiological exams, which can be selected for analysis. Collaboration is achieved when two users load the same slice and one of them, for example, changes the position of a cursor to show a point of interest. At the same time, the other user will see the movement of the cursor. If another physician enters the session, the others are immediately noticed through a list of on-line users in the browser.



TeleMed graphical patient records [TeleM99a]
Figure 5

The Shastra environment provides facilities for media-rich interaction in the context of shared visualizations. It has a rendering and visualization tool called Poly that encapsulates graphical object manipulation, rendering and visualization functionality. Poly interoperates with other Shastra tools and provides a very high level abstraction for manipulating graphical data. A collaborative session is initiated when one of the Poly users becomes the group leader and specifies the list of other users who will be invited to participate in the session. After being invited, users who accept are incorporated into the session. A shared window is created in which all cooperative interaction occurs, allowing a fully shared control. A participating user can leave an ongoing session at any time. Collaborating users can introduce graphics objects into the session, adjust visualization modes and parameters, and modify viewing modes and direction.

5. DISCUSSION

With the widespread use of WWW, new technologies were introduced, and a growing number of users aim to change their systems platforms into this new environment. One of such tendencies is using the Web as a wide collaboration environment. At present, we can find several projects underway to extend the capabilities of the Web to support collaborative activity, several systems that were developed for the Web as well as frameworks that were designed to allow the development of Web based collaborative environments [Bajaj97a].

The hardware support for these systems ranges from PC-based to high-end graphical workstations. Although VR devices are being used in many applications to provide more natural user interaction, in collaborative systems their use is still experimental. One example of VR environment is the augmented reality system *Studierstube* [Fuhrm99a] that allows collaboration of multiple users by means of 3D interactive devices and a stereoscopic real-time display. Moreover, since medical procedures rely mainly on touch, there is also a growing interest in the use of haptic displays. However, the use of this technology in collaborative systems is still in the beginning, mainly due to its accuracy and cost problems.

Collaborative applications were designed to operate mainly in *Unix* platforms. *Windows NT* is seldom used. This occurs because of network and security features of *Unix*. As a consequence *Motif*-based user interfaces are very used. Java has emerged as a first-class programming language that has been frequently used, especially because it has cross-platform portability and borrows heavily from the syntax of C++ while avoiding many of its features that lead to programming errors. *Virtual Reality Modeling Language* (VRML) and CORBA are also found as useful. Some authors study the use of VRML to support visualization applications in multi-user shared environments [Loveg98a].

The use of CORBA is advocated as suitable to make queries in distributed databases, because of its independence from language and operating system [Vogel97a]. Furthermore, with the definition of CORBAmed, which is a standard interface to many healthcare “Object Oriented Services” across most usual platforms, compatibility to a much wider range of software components is provided [Forsl99b]. There are some alternatives to the CORBA use to connect remote agents: sockets, message passing and *Remote Method Invocation* (RMI). While CORBA allows working with several languages in different nodes of a distributed system, RMI just allows integrating C/C++ codes using native methods in Java. They are also considered as complementary systems, because they each suit different needs [Farle98a, Carib99a]. Nowadays it’s noticeable a tendency towards CORBA use. TeleMed has already used this interface and future extensions of TeleInViVo will include it.

Concerning to communications issues, few collaborative systems are already using the facilities of the Internet like TeleMed and Shastra do, since these systems can be called from a browser. TeleMed also supports interactive real-time collaboration among several users providing video and audio annotation tools. TeleInViVo supports communication through TCP/IP, and has the advantage of using compression methods to allow transmission of a large volume of data. In this system, a new session begins only when a user calls other using a remote IP address. Similarly, a collaborative session in Shastra begins when one user (the leader) specifies and invites others through an Ethernet network providing facilities for media-rich interaction over the context of shared visualizations. SDSC_NetV is an experimental system concerned about the performance of volume rendering, so there is no explicit collaboration among users. In this system, several computational resources are connected in a network and can be used by any user. Recently there is a growing interest to migrate to ATM networks, mainly because of its greater velocity.

Considering the physicians' visualization and query needs, TeleInViVo, TeleMed and Shastra are the more complete systems. The first one offers a great variety of visualization tools and works with the most common medical image types, which are acquired through computed tomography, magnetic resonance imaging, PET and ultrasound. However, the second one is easier to be accessed through the Internet and tries to create a standard for medical database that can be accessed from the entire Web. Shastra provides a variety of mechanisms for visualizing multidimensional data, and SDSC_NetV tries to achieve a better volume rendering performance but does not offer many facilities to analyze and explore a specific volumetric data set.

Interaction is a very important issue in the development of collaborative visualization systems. To provide for efficient interaction in such applications we need to include, for example, the following tools: annotation, authoring, pointing and selection in shared views of data, shared whiteboard and synchronization. Visualization tools include user-specified visual representations, multiple views of data and rendering at different levels of resolution or using a partial set of data. Considering interaction and visualization, it's also important to specify communication, data management and data retrieval issues. In the first case the possibility of distributing data, code or image is needed. Data management includes the use of a centralized or distributed database, dealing with security and control of access to data generated by different users. Data retrieval involves a visual query language, associated visualization tools, and recording of queries [Freit97a].

According to previous reports in the literature, some of them mentioned earlier, many challenges face both users and developers, especially in systems for the medical area. Among the many features that need to be worked on in collaborative visualization systems, we can point out the communication technology to be used, an efficient identification handling, the coherence of shared data and synchronization of users activities. The creation of attractive and user-friendly interfaces to increase the physicians' interest is another challenge. Moreover, the problem to achieve real time visualization and interaction, mainly because of network traffic and interaction with large volume data using medical instruments still exists. Depending on the interactive application, touch feedback is also very important, but the high cost and low accuracy of VR devices difficult its use. The poor realism of images where faithful skin and muscle textures are still missing, is another open issue. So, for sure, the building of a collaborative system is an interdisciplinary effort that needs a user-centered approach, an efficient data management and object-oriented design and programming to provide reusability of code [Green90a, Freit97a].

6. CONCLUSION

This work presented a brief introduction to scientific visualization applied to Medicine with emphasis in collaborative visualization. At present, there is a great variety of imaging acquisition modalities that can provide inputs to medical visualization systems. These systems are also being improved with new interactive visualization techniques and with virtual reality techniques and equipment. Surgery simulators started to be developed and used by several physicians and students.

Often, medical visualization systems are not used by only one person, that is, it can be necessary a group of people working together to draw a diagnosis for a difficult or rare disease, or to achieve a common research objective. With the WWW popularization, new technologies that allow the simultaneous analysis of large volumes of data by collaborators in remote sites were developed. Many medical systems are available using these new concepts and technologies, and some of them were described here, but they have to be improved to become attractive work tools to the researchers. This study provides a basis to identify some difficulties still found for the real utilization of such systems. For example the problem of achieving real time interaction and the poor realism in the images are still open questions.

REFERENCES

[Anupa94a] Anupam, V.; Bajaj, C.; Schikore, D. et al.: Distributed and Collaborative Visualization. *Computer*, Los Alamitos, CA, Vol. 27, No. 7, p. 37-43, July 1994.

[Bajaj97a] Bajaj, C.; Cutchin, S.: Web Based Collaboration-Aware Synthetic Environments. *Proc. Of TeamCAD Gvu/Nist Workshop on Collaborative Design*, p. 143-150, May 1997. Available at http://www.ticam.utexas.edu/CCV/projects/collabweb/papers/index.html (Oct. 99).

[Brodl92a] Brodlie, K. W.; Carpenter, L. A.; Earnshaw, R. A. et. al.: *Scientific Visualization – Techniques and Applications*. Berlin, *Springer-Verlag*, 1992, 284 p.

[Carib99a] Caribou Lake Software, Inc.: *RMI versus CORBA*. Available at http://www.cariboulake.com/techinfo/rmi_corba.html (Oct. 1999).

[Colem96a] Coleman, J. et. al.: TeleInViVoTM: Towards Collaborative Volume Visualization Environments. *Computers&Graphics*,Oxford, Vol. 20, No. 6, p. 801-811, 1996.

[Colem99a] Coleman, J.: *Fraunhofer – Center for Research in Computer Graphics*. Available at http://www.crcg.edu/projects/medvis/TeleInViVo/Publicity/cyberedge.html (Oct. 1999).

[Earns92a] Earnshaw R. A.; Wiseman, N.: *An Introductory Guide to Scientific Visualization*. Berlin, *Springer-Verlag*, 1992, 156 p.

[Elvin96a] Elvins, T. T.: Volume Visualization in a Collaborative Computing Environment. *Computers&Graphics*, Oxford, Vol. 20, No. 2, p. 219-222, 1996.

[Farle98a] Farley, J.: *JavaTM Distributed Computing*. Sebastopol, CA, *O'Reilly & Associates*, 1998, 368 p.

[Forsl99a] Forslund, D.: *TeleMed*. Available at http://www.acl.lanl.gov/TeleMed (Oct. 1999).

[Forsl99b] Forslund, D.: *CORBAmed*. Available at http://www.omg.org/homepages/corbamed/ (Oct. 1999).

[Fraun99a] Fraunhofer – Center for Research in Computer Graphics. *TeleInViVoTM Version 2.5.1 – GUI Overview*. Available at http://www.crcg.edu/projects/medvis/TeleInViVo/refman/gui-overview.html (Sep. 1999).

[Freit97a] Freitas, C. M. D. S.: *Challenges in the Development of Interaction and Visualization Tools for Collaborative Applications*. Brazilian Symposium on Computer Graphics and Image Processing, 10., 1997, Campos do Jordão, SP.

[Fuhrm99a] Fuhrmann, A; Löffelmann, H.; Schmalstieg, D. et al.: Collaborative Visualization in Augmented Reality. *IEEE Computer Graphics & Applications*, Los Alamitos, CA, Vol. 18, No. 4, p. 54-59, July/Aug. 1998.

[Goble95a] Goble, J. C.; Hinckley, K.; Pausch, R. et al.: Two-Handed Spatial Interface Tools for Neurosurgical Planning. *Computer*, Los Alamitos,CA,Vol.28,No.7,p.20-26,July 1995.

[Green90a] Greenes, R. A.; Brinkley, J. F.: *Radiology Systems*. Shortliffe, E. H.; Perreault, L. E. (Eds.), Medical Informatics. USA, *Addison-Wesley*, p. 324-365, 1990.

[Haase96a] Haase, H.: Symbiosis of Virtual Reality and Scientific Visualization System. *Computer Graphics Forum*, Cambridge, Vol. 15, No. 3, Aug. 1996. Presented work at EUROGRAPHICS, 1996, Futuroscope-Poitiers, France.

[Haber90a] Haber, R. B.; Mcnabb, D. A.: *Visualization Idioms: A Conceptual Model for Scientific Visualization Systems*. Nielson, G. M.; Shriver, B. D. (Eds.), Visualization in Scientific Computing, *IEEE*, p. 74-93, 1990.

[Jain89a] Jain, A. K.: *Fundamentals of Digital Image Processing*. Englewood Cliffs, New Jersey, *Prentice-Hall*, 1989, 569 p.

[Johns98a] Johnson, G.: Collaborative Visualization. *Computer Graphics*, New York, Vol. 32, No. 2, p. 8-11, May 1998.

[Keppe75a] Keppel, E.: Approximating Complex Surfaces by Triangulation of Contour Lines. *IBM Journal of Research and Development*, New York, Vol. 19, No. 1, p. 2-11, Jan. 1975.

[Kilma97a] Kilman, D. G.; Forslund, D. W.: An International Collaboratory Based on Virtual Patient Records. *Communications of the ACM*, New York, Vol. 40, No. 8, p. 111-117, Aug. 1997.

[Levoy90a] Levoy, M.: Efficient Ray-Tracing of Volume Data. *ACM Transactions on Graphics*, New York, Vol. 9, No. 3, p. 245-261, july 1990.

[Loren87a] Lorensen, W. E.; Cline, H. E.: Marching Cubes: A High Resolution 3D Surface Construction Algorithm. *Computer Graphics*, New York, Vol. 21, No. 4, July 1987.

[Loveg98a] Lovegrove, S.; Brodlie, K. W.: *Collaborative Research Within a Sustainable Community: Interactive Multi User VRML and Visualization*. Available at http://www.scs.leeds.ac.uk/stu/Research/publications.html (Sep. 1998).

[Palme94a] Palmer, J. D.; Fields, N. A.: Computer Supported Cooperative Work. *Computer*, Los Alamitos,CA,Vol.27,No.5,p.15-17,May 1994.

[Posto96a] Poston, T.; Serra, L.; Solaiyappan, M. et al.: The Graphics Demands of Virtual Medicine. *Computers & Graphics*, Oxford, Vol. 20, No. 1, p. 61-68, 1996.

[Rhode97a] Rhodes, M. L.: Computer Graphics and Medicine: A Complex Partnership. *IEEE Computer Graphics & Applications*, Los Alamitos, CA, Vol. 17, No. 1, p. 22-28, Jan.-Feb. 1997.

[Silva97a] Silva, M. R. M.: *RenderVox: an Interactive Volume Visualization Tool* . Porto Alegre: Instituto de Informática/UFRGS, Dez. 1997. (Research Report #TI 721, in portuguese).

[Spurr94a] Spurr, K.; Layzell, P.; Jennison, L.; Richards, N.: *Computer Support for Cooperative Work*. Chichester, UK, *John Wiley & Sons Ltd*, 1994, 246 p.

[Srini97a] Srinivasan, M. A.; Basdogan, C.: Haptics in Virtual Environments: Taxonomy, Research Status, and Challenges. *Computers&Graphics*, Oxford, Vol. 21, No. 4, p. 393-404, July/Aug. 1997.

[TeleM99a] TeleMed User Manual: *Graphical Patient Record (GPR) Window*. Available at http://www.acl.lanl.gov/TeleMed(Sep. 1999).

[Vogel97a] Vogel, A.; Duddy, K.: *JavaTM Programming with CORBA*. New York, *Wiley Computer Publishing*, 1997, 425 p.

[Weste96a] Westermann, B.; Hauser, R.: Non-Invasive 3-D Patient Registration for Image-Guided Skull Base Surgery. *Computers&Graphics*, Oxford, Vol. 20, No. 6, p. 793-799, 1996.

[Wood97a] Wood, J.; Wright, H.; Brodlie, K.: *CSCV- Computer Support for Collaborative Visualization*. Earnshaw, Rae; Vince, John; Jones, Huw(Eds.), Visualization & Modeling, London,UK, *Academic Press*, 1997, p. 13-25.

[Yagel96a] Yagel, R.; Stredney, D.; Wiet, G. J. et al.: Building a Virtual Environment for Endoscopic Sinus Surgery Simulation. *Computers&Graphics*, Oxford, Vol. 20, No. 6, p. 813-823, 1996.

[Zajtc97a] Zajtchuk, R.; Satava, R. M.: Medical Applications of Virtual Reality. *Communications of the ACM*, New York, Vol. 40, No. 9, p. 63-64, Sep. 1997.